The other side of magic: The psychology of perceiving hidden things

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The other side of magic: The psychology of perceiving hidden things

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Abstract

When magicians perform spectacles that seem to defy the laws of nature, they do so by manipulating psychological reality. Hence, the principles underlying the art of conjuring are potentially of interest to psychological science. Here, we argue that perceptual and cognitive principles governing how we experience hidden things and reason about them play a central role in many magic tricks. Different from tricks based on many other forms of misdirection, which require considerable skill on the part of the magician, many elements of these tricks are essentially self-working because they rely on automatic perceptual and cognitive processes. Since these processes are not directly observable, even experienced magicians may be oblivious to their central role in creating strong magical experiences and tricks which are almost impossible to debunk, even after repeated presentations. We delineate how insights from perceptual psychology provide a framework for understanding why these tricks work so well. Conversely, we argue that studying magic tricks that work much better than one would intuitively believe provides a promising heuristic for charting unexplored aspects of perception and cognition.

Introduction

"Again there was surprise and amusement, now at the paradoxical duality of the experience: what was visually appearing to be true, was simultaneously known as being false" (Nielsen, 2008, p. 1505).

In stage magic, conjurers create magical experiences by fooling the minds and the senses of their audience, and they are highly successful in doing so. Indeed, when enjoying a good magical show, spectators often say that they "cannot believe their eyes". Because magicians manipulate perceptual and cognitive reality (rather than physical reality), it seems evident that psychologists should be highly interested in what they do and why it works. Yet, as several authors have pointed out, this potentially rich source of psychological insights has been largely untapped by academic psychology (Kelly, 1980; Gregory, 1986; Kuhn, Amlani, & Rensink, 2008; Macknik, King, Randi, & Robbins, 2008; Rensink & Kuhn, 2015; Thomas et al., 2015), and the scientific investigation of the psychological principles exploited by practicing magicians has only recently developed into a focused and coherent research program.

The most obvious link between stage magic and psychological research is the area of visual attention (Lamont, Henderson, & Smith, 2010, p. 19), and the rather surprising effectiveness and robustness of many magical routines can be understood in light of psychological research on *change blindness* and *inattentional blindness* (see Memmert, 2010; Kuhn & Tatler, 2011, for debate on relationship between inattentional blindness and misdirection). Research on change blindness (Rensink, O'Regan & Clark, 1997; Simons & Levin, 1997; Simons & Rensink, 2005) demonstrates that quite dramatic changes in a visual scene, which are readily noticeable if they occur in isolation, are extremely difficult to detect if they are accompanied by synchronous motion signals in other regions of the scene. Similarly, research on inattentional blindness (Mack & Rock, 1998) shows that rather conspicuous changes near to or even at the point of fixation – that is, right in front of our eyes – mostly go unnoticed if the observer is attending to something else. An important feature of this line of research, which undoubtedly has contributed much to its huge impact in cognitive science and appeal to the general public, is that it demonstrates a striking failure of *visual metacognition* (Levin, 2002). That is, it reveals a huge gap between what we *actually* perceive and what *we intuitively believe* we are able to perceive.

To the practicing magician, such failures of visual metacognition provide an excellent tool for producing a strong magical experience (Kuhn et al., 2014). If you can prevent the spectators from seeing something they are confident they would be able to see if it happened, you have a unique opportunity to do something that they will firmly believe never happened. For instance, as the findings of Kuhn, Tatler, Findlay and Cole (2008) show, you can let a cigarette fall into your lap right in front of their eyes, but they will typically fail to notice it if you have directed their attention elsewhere. Since the spectators firmly believe that they would notice such an obvious event occurring right in front of their eyes, they will later have a very hard time figuring out why the cigarette is no longer in the hand where it is supposed to be.

Performing a trick based on attentional misdirection typically requires considerable skill on the part of the magician, but it also requires a considerable amount of boldness. This boldness is needed because the idea that you can let a cigarette fall into your lap in plain view without anybody noticing is highly counter-intuitive. Accordingly, novice conjurers, who still rely on their natural intuitions, are often tormented with 'magician's guilt', i.e. the fear that the spectators will immediately notice how the trick is done. More experienced conjurers coach their apprentices not only by providing advice on how to improve their technical skills of misdirection, but also simply by ensuring them that their intuitive fear of getting caught is largely unwarranted. Indeed, learning to let go of this intuitive fear is often regarded as an important stage in the development of aspiring magicians, which makes them more confident, and in turn, more successful in actually performing the technical aspects of the misdirection in a convincing way. With increased practice and experience, magicians learn to overcome their natural intuitions. However, while misdirection is easier than one would intuitively expect, the skill and technique of the magician nevertheless often play a pivotal role.

The purpose of the present paper is to draw attention to a largely neglected factor in magic, which we believe is of great practical and theoretical importance, but tends to escape the attention of magicians because it is, to a much greater extent than many other forms of misdirection (see Kuhn et al, 2014, for an overview), independent of the magician's skill. Because this factor exerts its influence without any effort on the part of the magician, it tends to go unnoticed. Ironically, another reason why this factor is easily missed or underestimated is that it is even more powerful, robust and foolproof than many other forms of misdirection (such as attentional misdirection, for instance): The magician hardly needs to think about it because it almost always works.

The factor we have in mind is our intuitive experience of and reasoning about hidden things. It is obvious that the hiding of objects plays a central role in magic. When objects magically materialize it is mostly because they were kept well hidden just before, and when they magically disappear it is mostly because the magician suddenly hides them (Gibson, 1982). What is not so obvious, though, is that our experience of hidden things is much more strongly determined by automatic perceptual and cognitive heuristics beyond our conscious control than we intuitively believe and that these automatic processes constrain our conscious thinking and impede our problem-solving abilities. At the level of conscious reasoning, we all know that we cannot know for certain what might or might not be hidden behind an object in the foreground. However, automatic perceptual and cognitive processes induce intuitive beliefs or gut-feelings about the presence or absence of things behind an occluder that are so strong and convincing that we do not even consider questioning them, even though they might well be wrong (and, in the case of magic tricks, usually are).

Experiencing hidden things: The counter-intuitive phenomenon of amodal completion

Our current scientific understanding of these automatic processes owes much to the pioneering research of Michotte (Michotte, Thinès, & Crabbé, 1964/1991) and Kanizsa (1979) on a phenomenon they called *amodal completion*. An example of this phenomenon is shown in Fig. 1. The hardly identifiable fragments shown in panel (a) are immediately and effortlessly perceived as complete B's in panel (b). Furthermore, one has a strong feeling that the parts of the B's hidden behind the ink blot in panel (b) are 'really there' although they are invisible and may, in actual fact, very well be absent. If one were to remove the ink blot and see nothing behind them but gaps between the visible fragments (as in panel (a)) one would be thoroughly surprised, although one must admit that this is logically possible. The curious feeling that the hidden parts of the B's are really there, although they are not seen in the literal sense of the word, is traditionally described by saying that they are 'amodally present' (Michotte, Thinès, & Crabbé, 1964/1991). The historical reasons for the Michotte et al.'s (1964/1991) choice of the term 'amodal' are of limited interest here. Essentially, the term just serves to indicate the curious feeling that the hidden parts are really there and that they have a definite shape, although they are obviously not experienced in quite the same way as directly visible object regions[1].

XXXXXXXXXXXXXXXXXX Figure 1 about here XXXXXXXXXXXXXXXXXXXXXX

All extant theories of this phenomenon appeal to various more or less literal incarnations of the idea that the visual system somehow completes the directly visible parts of objects via some kind of extrapolation of contours, surfaces or volumes. Hence, one traditionally speaks of amodal *completion* (van Lier & Gerbino, 2015). Next, we shall consider some examples of how this general

[1] The interested reader may refer to Michotte, Thinès, & Crabbé (1964/1991) for more details about this definition.

phenomenon is exploited in magic tricks and how it impedes our ability to figure out how the tricks work.

Fig. 2(a,b) illustrates the well-known Gestalt principle of good continuation (Wertheimer, 1923/2012). When the two patterns in Fig. 2(a) are brought into register, a radical perceptual reorganization is experienced, where a curved wave pattern superimposed on a square wave pattern suddenly pops out. The essential idea here is that the visual system tends to group contour elements together when one contour element is a "good continuation" of the other. This general principle (or its modern incarnations, e.g. Kellman & Shipley, 1991) is thought to underlie many cases of amodal completion. If you cover the central X-shaped part of the "triangle" in Fig. 2(c) (say, with your thumb), you will have the impression of a complete regular triangle behind your thumb. This may be said to occur because such a regular triangle is the smoothest and most natural continuation of the visible contours. Similarly, if you cover up the central part of the two curves in Fig. 2(d), you will have the experience of a complete cross. Again, this is the simplest continuation of the visible contours. Note that these experiences are quite compelling even though you know very well that there is no complete triangle (in panel c) or cross (in panel d) behind your thumb.

XXXXXXXXXXXXXXXXXX Figure 2 about here XXXXXXXXXXXXXXXXXXXXXX

Based on this principle, it is quite easy to create a stunning spoon-bending illusion. As illustrated in Fig. 3, the simple secret behind the trick is to use a spoon which has already been bent in advance as well as a spare spoon-handle already cut off from another spoon. By aligning the spoon-head of the bent spoon with the spare handle and hiding the point of contact and the handle of the bent spoon behind your fingers you create the illusion of a single straight spoon. Working from there, you just let the spare spoon-handle fall slowly into the palm of your hand by releasing the pressure of your fingers. Once it is down in your hand you pull the bent spoon out with your other hand and show it to the audience.

XXXXXXXXXXXXXXXXXX Figure 3 about here XXXXXXXXXXXXXXXXXXXXXX

Many other magic tricks rely on the same principle. Barnhart (2010) mentions a few examples, such as the Chinese linking ring routine[2], in which solid rings appear to link and unlink by magically passing through each other. As illustrated in Fig. 4, the main secret behind the trick is that one of the rings actually has a gap in it. When this gap is occluded by the magician's hand, however, it amodally completes into an unbroken ring (Fig. 4b).

XXXXXXXXXXXXXXXXXX Figure 4 about here XXXXXXXXXXXXXXXXXXXXXX

Note that attentional misdirection plays at best only a subordinate role in these tricks . Nevertheless, they seem to create magical experiences which are no less impressive than those evoked by tricks where attentional misdirection is the main factor (even though the secrets behind these tricks are disappointingly simple once you know them). Indeed, they may be even more difficult to debunk because it will be of little use to change what you attend to when viewing the trick a second time. It is also interesting to consider that with tricks based on attentional misdirection, every sense of magic is lost once you know how the trick works. In the aforementioned cigarette trick, for instance, knowing that the magician just drops the cigarette into his lap in plain view will make you notice this. The tricks based on amodal completion, in contrast, retain a certain residual magical quality even when you know what is going on. Even though you know that the spoon is not complete, it still looks very convincingly like a complete spoon. Magicians sometimes refer to this kind of residual magic as "eye candy" and use it in entertaining "visual jests" (Ortiz, 2006). The art

[2] see http://www.youtube.com/watch?v=hnMcuODZ-UY, movie last accessed on Jan. 16th, 2016.

of the magician/comedian *The Amazing Johnathan*, for instance, is replete with excellent examples of this.

A further instructive example is the knife-through-arm routine[3], in which the magician creates the illusion of cutting through his own arm. Although this trick is extremely compelling (and repulsive), the basic underlying method is very simple: A portion of the blade is cut out to make room for the arm (Fig. 5(a,b)). This example is theoretically slightly more complicated than the previous ones, because it involves two competing tendencies to good continuation: Smooth continuation of the blade versus smooth continuation of the arm. At first blush, one may be tempted to assume that the former dominates the latter due to our explicit knowledge of the world: We know that flesh is softer and more likely to be cut by a knife than the other way around. Contrary to this seemingly plausible explanation, however, the illusion persists if the knife is substituted by a banana and the arm is substituted by a brick (see Fig. 5(c)). As shown by Gerbino and Zabai (2003), who created the banana-through-brick illusion, which of the two objects is perceived to penetrate the other seems to be determined by idiosyncratic heuristics more characteristic of perceptual processing than rational thought. Essentially, they found a) that the object which is on top tends to penetrate the other and b) that the smaller object tends to penetrate the other. These tendencies do not only explain why the knife is perceived to penetrate the arm but also why the banana is perceived to penetrate the brick. Vrins, de Wit and van Lier (2009) have presented evidence that perceived material hardness may also play a certain role, in the sense that soft materials are more readily perceived as being penetrated. In the case of the knife-through-arm routine, this can be expected to enhance the illusion further.

XXXXXXXXXXXXXXXXXX Figure 5 about here XXXXXXXXXXXXXXXXXXXXXX

[3] see http://www.youtube.com/watch?v=3eDCHC01VVo, movie last accessed on Jan. 16th, 2016.

The immediate and almost visceral nature of the illusion is nicely demonstrated in *The Amazing Jonathan's* brilliant performance of it[4]. Even before the trick starts, Jonathan starts yelling to the audience—"it's a trick, it's a trick". Yet, the audience not only perceives the knife to penetrate the arm, they also experience it as utterly real (Michotte, 1991; Mausfeld, 2013; Leddington, in press) and correspondingly repulsive.

Although most of the early research on amodal completion focused on the completion of image contours, the general phenomenon is not limited to the completion of image contours and objects occluded by other objects in the foreground. Rather, in so-called amodal volume completion (Tse, 1999; van Lier, 1999; van Lier & Wagemans, 1999), the visible surface of a full-fledged three-dimensional object can complete amodally into the entire boundary surface of a volumetric surface. Thus, to borrow an example from van Lier (1999), "seeing" the backside of a tree-trunk can also be considered as an instance of amodal completion.

The well-known *Chicago multiplying billiard balls routine* provides a good example of the role of amodal volume completion in magic (see Fig. 6)[5]. Here, the conjurer begins by holding a single ball between two of his fingers, which suddenly and apparently inexplicably turns into two balls (and so on). The essential secret behind the trick is that one of the balls is a hollow shell, from which the other one is conveniently produced. If you look at Fig. 6(a), you have an impression of four solid balls, but in reality, one of them is just a hollow shell (Fig. 6(b)).

XXXXXXXXXXXXXXXXXX Figure 6 about here XXXXXXXXXXXXXXXXXXXXXX

[4] See http://www.youtube.com/watch?v=3eDCHC01VVo, movie last accessed on Jan. 16th, 2016.

[5] See also http://www.youtube.com/watch?v=seaO1c5awYw for a demonstration, movie last accessed on Jan. 16th, 2016.

It is important to point out that the illusory experience of a complete ball persists even when you know it is actually just a semi-spherical shell. Indeed, using an empty shell such as the one used in this trick, you can even create a compelling illusion where the shell seems to morph into complete ball while you hold it in your hand simply by lifting it off a table (Ekroll, Sayim & Wagemans, 2013). Furthermore, putting your finger into such a semi-spherical shell does not ruin the perceptual impression of a complete ball. Rather, it leads to an illusion of bodily awareness, in which the finger feels shorter, as if to make space for the illusory volume of the ball (Ekroll et al., 2016). This strength of the tendency to immediately experience the shell as a complete ball neatly explains why it is very difficult to debunk this trick, even after repeated viewings (Danek, Fraps, von Müller, Grothe, & Öllinger, 2014).

Amodal absence

As already mentioned, extant theories of amodal completion appeal to various more or less literal incarnations of the idea that the visual system somehow completes the directly visible parts of objects via some kind of extrapolation of contours, surfaces or volumes. Hence, the traditional term amodal *completion* seems quite apt. However, an intriguing and rather rude illusion recently circulating on the internet suggest that this idea might fall short of capturing all of the relevant phenomena and this may have interesting implications for our understanding of how many magic tricks work. We are referring to the illusion of "amodal nudity" (e.g. Hill, 2013; Bonnet, 2013) where various bathing-suit models look strikingly naked, although they are actually wearing proper attire, which just happens to be occluded. Various blog posts on the internet (e.g. Hill, 2013) will try to convince you that this effect has something to do with your dirty mind, but this "theory" is easily disproven. As illustrated in Fig. 7, essentially the same effect can be achieved with considerably less erotic material, such as a cluttered office desk. Notice how difficult it is to imagine that the clutter on the office desk (Fig. 7(a)) is really there behind the "bubbled" occluder (Fig. 7(b)). To appreciate the striking nature of this illusion even better, do the following experiment. First look at the unoccluded picture (Fig. 7(a)), close your eyes and try to imagine the clutter on the desk before your “inner eye”. Now, repeat the experiment, but rather than closing your eyes, look at the occluded version of the picture (Fig. 7(b)) while you try to imagine the clutter behind the occluder. You will probably find that the latter is considerably more difficult. Thus, it would seem that merely viewing the occluder somehow interferes with your ability to imagine things behind it (even things you *know* are actually there). The demonstration in Fig. 8 shows that an object which is expected to be there based on high-level expectations can also be experienced as curiously “absent” when it is hidden behind and aptly positioned occluder[6]. This shows that we are dealing with some kind of active perceptual suppression rather than a mere failure to represent invisible things.[7]

Even though this effect is rather counter-intuitive, it is not difficult to explain in terms of general heuristics known to play a central role in perceptual processing. The basic idea is that the perceptual system tends to avoid interpretations of the visual input that involve unlikely coincidences and alignments along the line of sight (Biederman, 1987; Freeman, 1994). In this case, the interpretation that the clutter is really there behind the occluder would mean that all of the clutter is positioned such that it is covered by the few and rather small hiding places actually provided by the occluder, which is highly unlikely to happen by chance. Even small displacements of the occluder or the clutter would make parts of the clutter visible. Hence, the perceptual system seems to discard the possibility that the clutter is actually there behind the occluder.

XXXXXXXXXXXXXXXXXX Figure 7 about here XXXXXXXXXXXXXXXXXXXXXX

XXXXXXXXXXXXXXXXXX Figure 8 about here XXXXXXXXXXXXXXXXXXXXXX

[6] As pointed out by an anonymous reviewer, a factor that may make it difficult to imagine the objects in Fig. 7(a) as hidden behind the ”bubbled” occluder in Fig. 7(b) is that they are perceived as larger than the relevant parts of the ”bubbled” occluder (which is experienced as being located in the foreground) due to size-distance invariance (Emmert’s law, see Holway & Boring, 1941). It is a simple geometrical fact that a small object in the foreground can occlude the view of a much larger one in the background provided that it is sufficiently far away, but it may be untuitively difficult to imagine this.

[7] This may also explain the curious experience evoked by viewing a face covered by an apple in Magritte’s well-known painting “The Son of Man”, where there is “a sort of conflict […] between the visible that is hidden and the visible that is present” (Torczyner & Magritte, 1977, p. 172).

This phenomenon is similar to the amodal presence of the hidden parts of the B's in Fig. 1(b) in the sense that both phenomena are positively different from not having any particular perceptual experience at all (which one might presume to be the case because there is no corresponding sensory input). At the same time, the two phenomena also seem to be complementary in two respects. While the perceptual system produces a *positive* and *specific* percept in Fig. 1(b), it seems to produce a *negative* and *unspecific* percept in Fig. 7(b). In order to highlight both the similarity and the complementarity vis-à-vis the well-known phenomenon of amodal presence, we propose to refer to the new phenomenon as "amodal absence". To emphasize that "amodal absence" is different from the mere lack of any particular perceptual experience (due to a lack of direct sensory input), we may refer to the latter as *modal* absence. While total occlusion will always imply that no perceptual objects are instantiated (they are modally absent), amodal absence means that an abstract set (see below) of possible objects which could, in principle, be hiding behind the occluder, is actively excluded by the perceptual system.

Clearly, when one looks at Fig. 7(b), it is not only the particular objects in Fig. 7 (a) that are amodally absent, but also a larger set of other logically conceivable possibilities. But exactly how large is this set, and how can it be characterized? An extreme hypothesis would be that the perceptual system excludes every logically possible object that may lie hidden behind the occluder. On this hypothesis, the phenomenon of amodal absence could be described as some kind of amodal completion of empty space. This extreme hypothesis seems implausible, though, because it would make little sense for the visual system to categorically exclude the far from unlikely possibility that some object may lie hidden behind the occluders. A more plausible hypothesis, therefore, is that it excludes some, but not all of the possibilities. This idea can be appreciated by considering van Lier's (1999) demonstration of 'fuzzy' amodal completion (Fig. 9). The different alternatives B1-B3 all look like plausible completions of the partially occluded shape in panel A, but the different alternatives C1-C3 do not. In our terminology, one may say that the alternatives B1-B3 are all to some extent amodally present, while the alternatives C1-C3 are to some extent amodally absent.

As illustrated in Fig. 10, classical amodal completion, van Lier's (1999) fuzzy amodal completion, and the perceptually even more unspecific experience of amodal absence (Fig. 7(b)) can all be regarded as resulting from the same overarching logic of inference operating at different levels of stimulus ambiguity. In the example of classical amodal completion (Fig. 7(a)), the perceptual experience is highly specific because the highly regular visible part provides strong cues to the shape of the hidden part. In the example of fuzzy amodal completion (Fig. 7(b)), the visible part is still available, but provides a poorer basis for perceptual inference because it is less regular, which results in a less well-specified percept. In the example of amodal absence (Fig. 7(c)), there is no visible part, but some limited form of perceptual inference is still possible based on the size and shape of the occluder itself. Although an object of the same (retinal) size and shape as the occluder can, in principle, be hidden behind the occluder, this necessarily requires a perfect alignment of the occluder and the hidden object along the line of sight, which is highly unlikely to happen by chance in a natural real-world scene. The smaller an object is relative to the occluder, however, the more likely it becomes that it could have become totally hidden behind the occlude by mere chance. Thus, based on the well-known idea that the perceptual system tends to avoid interpretations involving unlikely coincidences (Rock, 1983; Biederman, 1987; Freeman, 1994) we may speculate that amodal absence does not involve the perceptual exclusion of all possible objects, but only those which are particularly unlikely based on cues such as their size and shape relative to the occluder.

XXXXXXXXXXXXXXXXXX Figure 9 about here XXXXXXXXXXXXXXXXXXXXXX

XXXXXXXXXXXXXXXXXX Figure 10 about here XXXXXXXXXXXXXXXXXXXXXX

This kind of amodal absence may play an important role in many magical tricks. Consider, for instance, a trick where the magician shows an empty palm and then, with a swift flick of the wrist, seems to grab a coin out of thin air. The simple secret behind this trick is that the coin is kept hidden behind the magician's thumb (Fig. 11). During the quick flick of the wrist, it is simply pulled out using the index and middle finger. It is clear that this trick involves some misdirection. The small movements of the fingers tend to go unnoticed because of the much larger movements of the hand (Hergovich, Gröbl, & Carbon, 2011) and the magician might look into the air to direct attention away from the hand during the critical move. However, the belief that the hand was actually empty before the critical move may be significantly reinforced by the kind of amodal absence also evident in the "tidy-up-your desk illusion" (Fig. 7). In this case, too, accidental alignment (of the coin and the thumb) along the line of sight is presumably the driving principle. From the perspective of the magician, it is easy to see the significance of the elements of misdirection elements involved in this trick, because he or she actively performs them. It may be less obvious, however, that the clever hiding of the coin not only hides the coin, but also produces a compelling impression of absence which adds to the overall robustness and strength of the routine.

XXXXXXXXXXXXXXXXXX Figure 11 about here XXXXXXXXXXXXXXXXXXXXX

In the above, we have only considered the phenomenon of amodal absence in connection with static configurations. As beautifully illustrated by Richard Wiseman's video clip "The Ball"[8] dynamic cases of accidental alignment between the occluder and the hidden object seem to evoke even more impressive experiences of amodal absence. This can be regarded as a straightforward consequence of the increased level of accidentalness introduced by the carefully coordinated motion of the occluder and the hidden object.

Gibson (1982) has argued that a key aspect of the materialization and vanishing of objects typical of so many tricks is that the magician somehow hides the visible optical transitions (such as accretion and deletion), which normally occur when a hidden object becomes disoccluded or a visible one

[8] See https://www.youtube.com/watch?v=sIQ_8bIco3s, movie last accessed on Jan. 16th, 2016.

becomes occluded. This is undoubtedly the case, and the above coin example may be regarded as a case in point, where the gradual accretion of the hidden coin is hidden by means of misdirection. However, our analysis suggests that another significant factor may also be involved: The illusion of amodal absence.

In the above, we have introduced the term amodal *absence* to describe the compelling perceptual experience that "something *is not* there", as in Figs. 7 and 8. We conceive of this term as directly analogous and complementary to the established term amodal *presence*, which refers to the compelling perceptual experience that "something *is* there", as in Fig. 1. Amodal *presence* has hitherto only been discussed in connection with cases of *partial* occlusion, while we have primarily used examples involving *total* occlusion to demonstrate the phenomenon of amodal *absence*. This should not be taken to imply that amodal absence is limited to cases of total occlusion. Van Lier's (1999) fuzzy amodal completion (Figs. 9 and 10), for instance, clearly illustrates how cases involving partial occlusion can evoke both "amodal absence" and "amodal presence" and that they may be regarded as two sides of the same coin.

Magic, problem solving and visual fixedness

Trying to find out how a magical trick works can be considered as a problem-solving task (Danek, Fraps, von Müller, Grothe, & Öllinger, 2014). For magic to be effective, it is obviously of paramount importance that this problem-solving process is unsuccessful. The reader may be familiar with Duncker's (1945) classical idea of functional fixedness as an important factor impeding effective problem-solving. It is probably less well known, though, that Duncker (1945, p. 85) also related his general concept of "fixedness" to "factors such as visual organization". For instance, he pointed out that a "chimpanzee who stands in need of a stick (something long, firm …) sometimes has difficulties in recognizing the stick in a branch still growing on the tree, in seeing it as a percept apart […]. On the tree is a 'branch', a part of the figural unit 'tree', and this part-character—more generally, this '*fixedness*'—is clearly responsible for the fact that to a search for something like a stick, the branch is less 'within reach' than the branch on the ground." (p. 85). Fig. 12 provides a compelling demonstration of Duncker's point: Notice how difficult it is to recognize that the box in panel (a) is actually part of the 'grid' in panel (b).

XXXXXXXXXXXXXXXXXX Figure 12 about here XXXXXXXXXXXXXXXXXXXXXX

We believe that this line of thinking is very useful for understanding many aspects of magic in general, and the great robustness of tricks based on amodal perception (i.e. amodal completion *or* amodal absence) in particular. It is difficult for us to see the visible parts of objects in their own right, because after visual organization has taken place, they are but mere parts of more comprehensive figural units (Gestalts), like a complete ball with a backside, a complete spoon or an unbroken blade. From this perspective, it is easy to see why it is so difficult to debunk tricks based on amodal perception: In order to find out what is going on, the spectator has to consciously disregard the visual organization imposed by the perceptual system and mentally organize the visual input in a different way. Visual organization is a biologically important factor that, for the most part, allows us to make sense of the noisy, ambiguous and incomplete visual input actually available at our retinae (Koffka, 1935) and normally, there is no need to consciously reorganize the structure imposed by our visual system. Only in exceptional cases (like in magic tricks), the very same visual organization can backfire and also lead to misleading illusions.

Cognitive impenetrability

Visual fixedness may be thought of as a consequence of the cognitive impenetrability of perceptual processes (Pylyshyn, 1999; Firestone & Scholl, 2015). Consider the lightness illusion in Fig. 13.

Although you may find it difficult to believe, the chess figures in the top row are identical to the ones in the bottom row. The only reason why the upper figures look white while the lower figures look black is that they are viewed in different contexts (Anderson & Winawer, 2005; see also Adelson, 2000 and Gilchrist et al., 1999 for similar demonstrations). Importantly, even when you know that the figures are actually identical, they still look very different (white and black, respectively). Several authors have argued that amodal completion is independent of conscious knowledge (i.e. cognitively impenetrable) in much the same way as this lightness illusion (Michotte et al. 1964/1991; Kanizsa, 1979; 1985; Kanizsa & Gerbino, 1982; Pylyshyn, 1999). Some effects of learning and knowledge on our mental processing of occluded objects have been documented, (Vrins et al., 2009, Hazenberg et al., 2014, Hazenberg & van Lier, 2015), but it can be discussed whether these effects are part of what should be called amodal perception proper. Importantly, amodal perception is clearly less cognitively penetrable than attention, because endogenously-controlled attention can be voluntarily directed (Pylyshyn, 1999). This suggests that it should be even more difficult to debunk tricks based on amodal perception than tricks based on attentional misdirection. When people try to debunk a trick based on amodal perception, the cognitively impenetrable illusion (or visual fixedness) closes the door to the right solution even before any conscious problem-solving even starts.

XXXXXXXXXXXXXXXXXX Figure 13 about here XXXXXXXXXXXXXXXXXXXXXXX

Ortiz (2006, p. 37; see also Leddington, in press) has argued that magic "can only be established by a process of elimination"[9]. The properties of perceptual mechanisms make them seem perfectly suited for achieving this: One of the hallmarks of perception is that it tends to provide unique interpretations of the highly ambiguous sensory input (Hoffman, 2000). That is, the perceptual

[9] "Magic can only be established by a process of elimination. There is no way that you can directly apprehend that you're witnessing magic. You conclude that it's magic because there is no alternative. Therefore, the primary task in giving someone the experience of witnessing magic is to eliminate every other possible cause." (Ortiz, 2006, p. 37).

process typically involves the automatic, cognitively impenetrable, and essentially instantaneous elimination of a large (often infinite) set of alternative interpretations of the sensory input.

Magicians also often highlight the importance of setting up misleading assumptions and expectations in order to conceal the method behind a trick (Ortiz, 2006; Kuhn et al., 2014). Visual fixedness and the cognitive impenetrability of perceptual mechanisms may be regarded as an extreme form of this kind of generation of false assumptions that may be critical to the robustness and potency of many magic tricks. Importantly, the assumptions made by the visual system are not consciously made, making sure that the spectator never even suspects that their assumptions have been tampered with.

Duncker's (1945) concept of "visual fixedness" can be understood in two slightly different ways. We have highlighted how it may be a good metaphor for how cognitively impenetrable perceptual processes can impede conscious reasoning by automatically excluding the true explanation of a trick. On this reading, Duncker's concept of "visual fixedness" would not be entirely analogous to his concept of "functional fixedness", because the latter refers more to a learned (and potentially reversible) habit of thought than a perceptual process which is cognitively impenetrable in the absolute sense. We believe that the examples we have been considering are best understood as resulting from visual fixation in the former sense, but it may also be possible that some processes more akin to functional fixation in the second sense play a role in both perception and magic.

In the present paper, we have focused on demonstrating how amodal perception plays an important role in creating strong magic by virtue of being due to cognitively impenetrable perceptual mechanisms. Given that inferences about hidden things go far beyond the directly available sensory input, it may appear rather counterintuitive that it is partly based on perceptual mechanisms, but the potency of amodal perception in producing strong magic suggests that this is nevertheless the case. On a more general level, we believe that analogous lines of reasoning may help to further flesh out the role of genuinely perceptual mechanisms in making inferences about causality (Duncker, 1945, pp. 66-67; Michotte, 1963; Leslie, 1988; Scholl & Tremoulet, 2000; Ortiz, 2006, p. 54.), actions and intentions (Scholl, & Gao, 2013; Van de Cruys et al., 2015) or even realness (Michotte, 1991; Mausfeld, 2013; Vishwanath, 2013, 2014; Leddington, in press). Importantly, one could argue that it is the automatic nature of amodal perception that makes such a potent tool for creating robust and surprising magical effects. On this view, not only amodal completion, but perceptual processes in general can be expected to be particularly potent factors in magic (Ekroll & Wagemans, 2016).

According to a golden rule often appealed to by magicians, one should never repeat the same trick twice to avoid that the spectators notice how the trick works. In the case of tricks relying on attentional misdirection, this obviously makes sense. If, however, a trick is based on a cognitively impenetrable perceptual illusion, one would expect that it can be repeated essentially *ad libitum*. The only potential adverse effect of repeating the trick would be that the spectators gain more time to think, but even then the chances of figuring out how it works should be rather slim due to visual fixedness. Based on this reasoning, investigating the effect of repeated presentations of magic tricks on the spectators' likelihood of figuring out the method could be a promising tool for elucidating the nature of the mechanisms underlying different kinds of magic tricks. Recently, for instance, Cui et al. (2011) showed that a sleight-of-hand illusion traditionally believed to be based on social attentional misdirection is very resilient to repeated presentations, which may be taken to suggest that more automatic perceptual mechanisms are at play.

In terms of the taxonomy of misdirection recently proposed by Kuhn et al. (2014), magic based on amodal perception and other cognitively impenetrable perceptual effects fit nicely into the category of non-attentional perceptual misdirection. The present analysis is also consistent with their observation that magic based on "non-attentional perceptual mechanisms is more resilient to the spectator's own intentions" (p. 7) than magic based on attentional misdirection.

Failures of visual metacognition as a key factor in magic

In the introduction, we pointed out that the kind of inattentional blindness and/or change blindness that plays a central role in many magic tricks involves a systematic failure of visual metacognition, where spectators have unrealistic intuitions about how much they actually see. Our immediate phenomenology conjures up the misleading impression that our visual system does much more for us than it actually does. Interestingly, one may argue that amodal perception involves a similar systematic failure of visual metacognition. In this case, though, our immediate phenomenology conjures up the misleading impression that our visual system does much *less* for us than it actually does. We have a compelling impression of not being able to see hidden things, but the phenomena of amodal perception suggest that we actually do, at least in a functional sense. Thus, magicians can make the spectators see something that is not really there, while they are confident that they would only be seeing it if it were really there.

We believe that these failures of visual metacognition are essential for creating strong magical experiences because they make it almost impossible for the spectators to even suspect that they are being fooled. Hence, on a general level, one may argue that while attention and amodal perception are quite disparate phenomena in their own right, they both involve failures of visual metacognition, which accounts for their exceptional potency as tools for generating strong and robust magical experiences. In an even more general vein, it may prove rewarding to explore the hypothesis that also many other types of magic effects are based on analogous failures of visual metacognition that have yet to be systematically discussed and characterized. As discussed by Kuhn et al. (2014), an important feature of successful misdirection is that it should be counterintuitive. Relatedly, it is essential that the misdirection is not recognized as such. Yelling “look over there, a gorilla on a bike!” may distract people’s attention from a secret move, but it is obviously not a very good recipe for strong magic. Relying on a failure of visual metacognition, on the other hand, ensures both that the misdirection is counterintuitive (because failures of visual metacognition are counterintuitive) and that the misdirection is not recognized as such (because we are not consciously aware of our failures of visual metacognition).

As an example of a further counterintuitive aspect of perception that may qualify as a failure of visual metacognition, one may consider the perception of causality: While we naively tend to think that causality is inferred by conscious reasoning, there is ample evidence to suggest that it is also to a considerable extent experienced automatically based on perceptual mechanisms (Duncker, 1945, pp. 66-67; Michotte, 1963; Leslie, 1988; Scholl & Tremoulet, 2000; Ortiz, 2006, p. 54.).

Stupid tricks that fool most people most of the time: The role of psychological effects in magic

Our explorations of the role of amodal perception in magic described in the present paper were largely motivated by a general and simple heuristic that we believe may be useful for identifying further aspects of magic of particular interest for cognitive science. The basic idea is this: If a magical trick involves an unknown but potent psychological (perceptual or cognitive) factor, it is likely to produce an effect which is more stunning than you would expect based on a description of how it is done. Thus, conversely, if a given magic trick exhibits such a discrepancy between the expected and the actual potency of the effect, this may point to hitherto unknown or underestimated perceptual or cognitive phenomena contributing to the magical effect. In fact, if you leaf through an arbitrary instructional book on magic, you will probably notice that many of the tricks seem to fall into this category. You will also notice that most descriptions of how to do a particular trick are preceded by a description of how the spectators experience the trick. Often, this description is quite indispensable because it is far from obvious how the often quite simple and seemingly “stupid” methods being described are sufficient for creating a strong magical experience. That even magicians often lack a true and complete understanding of how many tricks work is suggested by the aforementioned phenomenon of magician’s guilt, which is a topic of concern vigorously discussed among practicing magicians: The magician has the feeling that the method behind his trick is so blatantly obvious that it must be evident to everybody. However, the experienced magician has one important advantage over the novice: Even if he does not really know why a particular trick works so well, he knows from experience that it will work like a charm.

In summary, the strategy of looking for magic tricks which work much better than one would expect based on a description of the method may turn out to be very useful for uncovering unknown psychological factors in magic in general.

Summary and conclusions

We have argued that automatic perceptual and cognitive mechanisms governing how we experience and reason about hidden things – in particular those underlying the well-known phenomenon of amodal presence and the less well-known, but presumably intimately related phenomenon of amodal absence –play a central role in many magic tricks. We have also argued the causal role of these mechanisms, which cannot be observed directly, is difficult to appreciate even for experienced magicians, and that it may therefore have been largely neglected in discussions of how magic works. We have also suggested that the surprising discrepancy between the expected and the actual efficiency of many magical routines may serve as a tell-tale sign of interesting psychological effects that may help guide further research into the psychology of magic.

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Figure 1: An example of amodal completion. When viewing panel (b) one automatically and effortlessly has the impression of complete B's partially hidden behind the black "ink blot", although only the fragments shown in panel (a) are directly visible. After Bregman (1981).

Figure 2: (a,b) Demonstration of the Gestalt principle of good continuation. When the two patterns in (a) are displaced towards each other such that the curved segments are brought into register (b), a radical perceptual reorganization is experienced, where a curved wave pattern superimposed on a square wave pattern suddenly pops out (after Herzog, Otto, Boi, & Öğmen, 2012). (c) If you cover the central X-shaped part of the triangle (say, with your thumb) you will have the experience of a complete regular triangle (after Michotte et al. 1964/1991). The percept of a complete regular triangle can also be explained in terms the principle of "good continuation": The perceptual completion of the contours is the smoothest and most natural continuation of the visible contours. (d) Similarly, if you cover up the central part of this figure, you will perceive a complete X.

Figure 3: Illustration of how a magician may rely on amodal completion to create a stunning illusion of spoon bending. First, the conjurer presents a seemingly complete and straight spoon (a), which then gradually bends (b). After the bending is complete (c), the magician pulls the bent spoon out of his hand and hands it to a member of the audience. As shown in (d), the spoon was actually bent from the very start, but a spare spoon handle is held in alignment with the head of the spoon. Since the gap between the head of the bent spoon and the spare handle is hidden by the finger, the spectator believes to see a single unbroken straight spoon. The illusion that the spoon is bending is created by letting the spare handle fall slowly into the palm of the hand (e). Afterwards, the bent spoon is pulled out of the hand and handed to a member of the audience (f), while the spare handle is kept hidden in the hand. Since the audience will be very occupied with examining the bent spoon, it is very easy to get rid of the spare handle without being noticed.

Figure 4: The main principle underlying the Chinese linking ring routine. One of the rings has a small opening (a), but when the opening is covered by the magician's fingers, the ring looks complete (b).

Figure 5: (a) The simple explanation behind the knife-through-arm trick is a hole in the blade. (b) When the arm is put into the hole, the knife appears to penetrate the arm, rather than the other way around.(c) Using essentially the same trick, it is also possible to create the illusion that a banana penetrates a brick (from Gerbino & Zabai, 2003).

Figure 6: In the Chicago multiplying balls trick, the conjurer starts with a single ball held between his thumb and index finger, and successively makes additional balls appear until he ends up with showing four balls, as in panel (a). The main secret behind the trick is that the "ball" kept between the thumb and the index finger is actually just an empty semi-spherical shell (top of panel (b)) in which a second ball can be hidden. At the beginning of the routine, one complete ball is hidden in the shell. Using the middle finger, this ball is then flipped out of the shell and held between the index finger and the middle finger. After having produced this basic illusion, more balls can be produced by surreptitiously loading new balls into the shell while pretending to move the upper ball one step up in the "ladder" of fingers using the other hand. Then, the newly loaded ball can be produced from the shell in the same way as before.

Figure 7: A demonstration of "amodal absence" inspired by a currently popular "visual joke" circulating in social media called "amodal nudity" or "bubble porn" (e.g. Hill, 2013; Bonnet, 2013). In panel (b), the objects on the table are occluded by a violet "bubbled" occluder. Note how difficult it is to imagine that the objects in (a) are really hidden behind the "bubbled" occluder in (b).

Figure 8: Although high-level knowledge makes us expect the middle finger to be there behind the banana, it is still experienced as curiously absent.

Figure 9: The shapes B1-B3 and C1-C3 are all logically possible completions of the partially occluded shape A. Some of them (B1-B3) are experienced as likely, while others (C1-C3) are experienced as unlikely. Thus, the perceptual representation of the hidden parts of the shape may be better conceived of as a set of possible shapes rather than a specific one. Reprinted from Acta Psychologica, 102(2), van Lier, R., Investigating global effects in visual occlusion: From a partly occluded square to the back of a tree-trunk. Pp. 203-220, Copyright (1999), with permission from Elsevier.

Figure 10: Illustration of how the perceptual system may generate increasingly fuzzy representations of occluded scene regions as the ambiguity of the stimulus increases. (a) The most well-known type of amodal completion. Here, the visual system creates a rather specific representation of the parts of the scene hidden behind the square: The visual system creates a representation which encompasses just a small subset (green disk) of the set of logically possible interpretations (dotted circle). (b) A more fuzzy kind of amodal completion (van Lier, 1999), where the visual system creates a representation encompassing a larger subset of the logically possible options. (c) In the case of total occlusion, the stimulus is even more ambiguous, but the visual system may create a representation which, although it is very fuzzy and unspecific, is more specific than the set of logically possible options. Hence, some of the logically possible representations would be eliminated by the visual system.

Figure 11: Simple coin production. The magician shows a seemingly empty hand, as in (a), and grasps a coin out of thin air. In reality, the coin is kept behind the thumb to begin with, as shown in (b).

Figure 12: An example of "visual fixedness": It is very difficult to see that the box in (a) is actually a part of the figure in (b). After Koffka (1935).

Figure 13: The chess figures on the top and on the bottom are actually identical, but the ones on top look white, while those at the bottom look black. Note that this illusion does not go away even though you know that the figures are in fact equal. You can verify this by covering up the surrounds. Reprinted by permission from Macmillan Publishers Ltd: Nature, Anderson, B. L., & Winawer, J. Image segmentation and lightness perception. Nature, 434(7029), 79-83, copyright (2005).

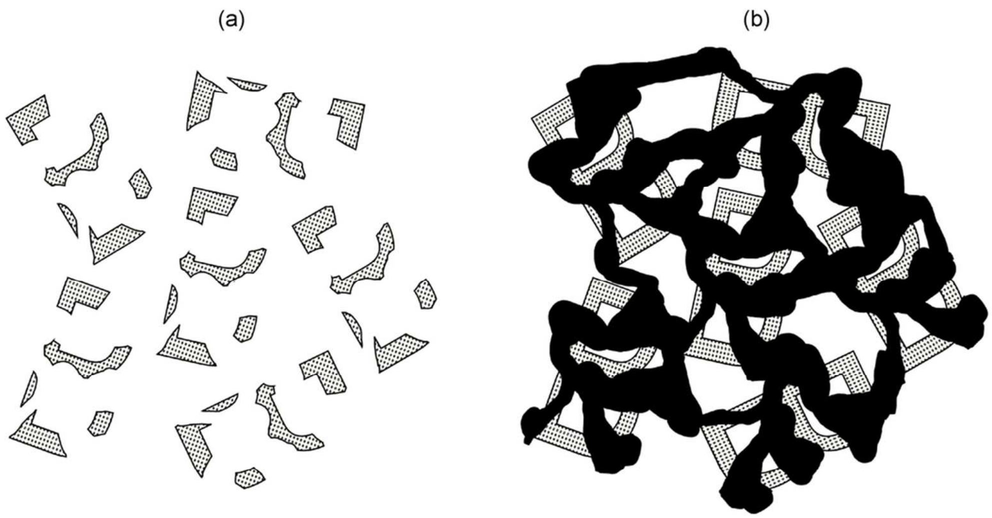
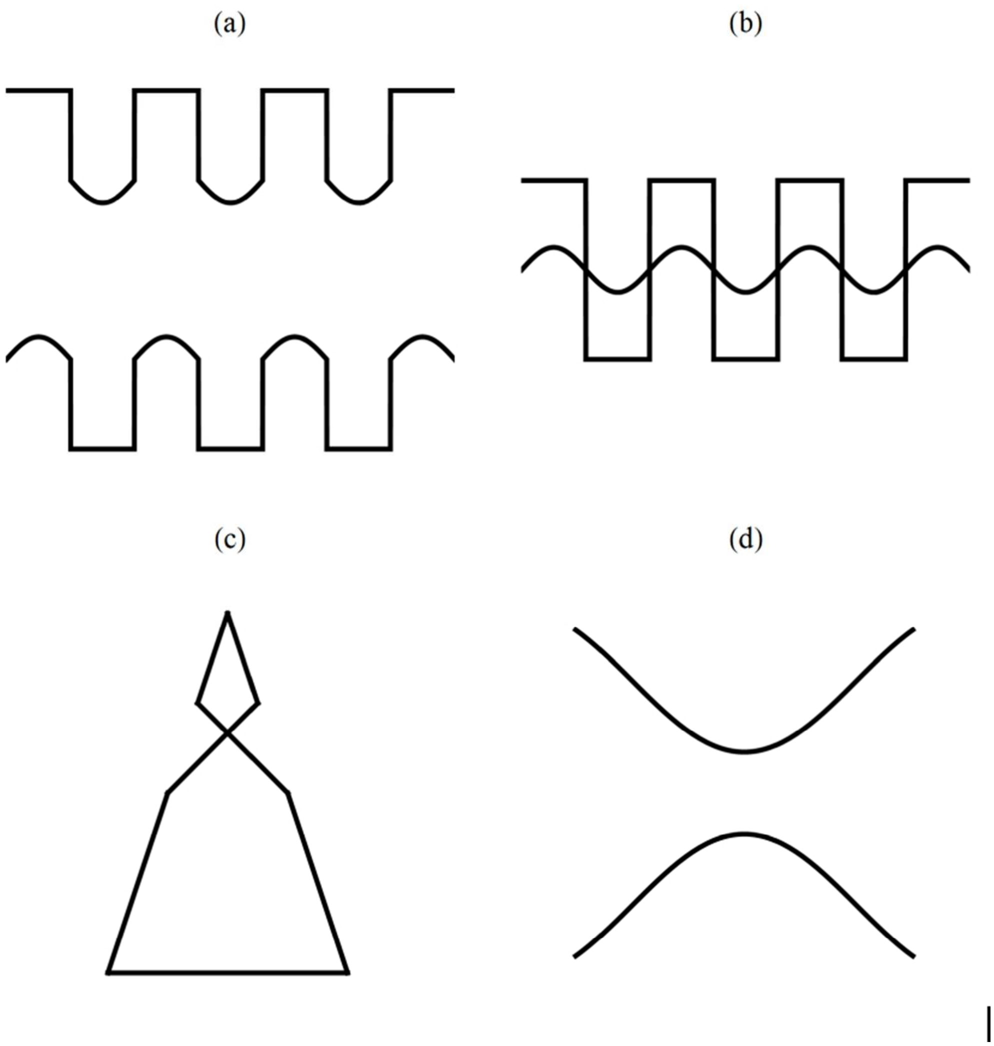


Figure 1: An example of amodal completion. When viewing panel (b) one automatically and effortlessly has the impression of complete B's partially hidden behind the black "ink blot", although only the fragments shown in panel (a) are directly visible. After Bregman (1981).
90x50mm (300 x 300 DPI)



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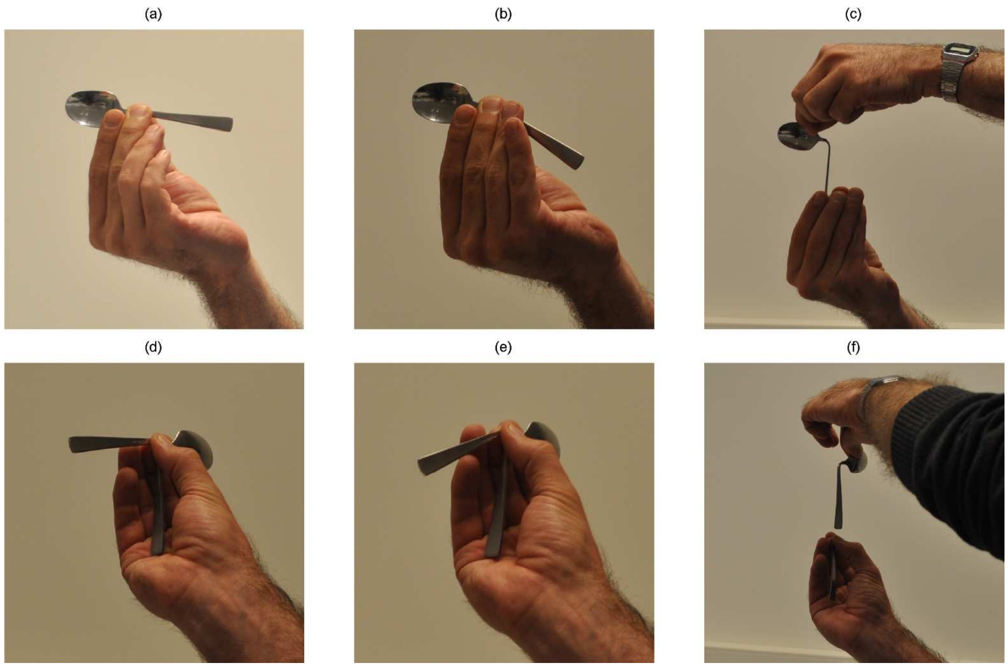

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238x158mm (300 x 300 DPI)

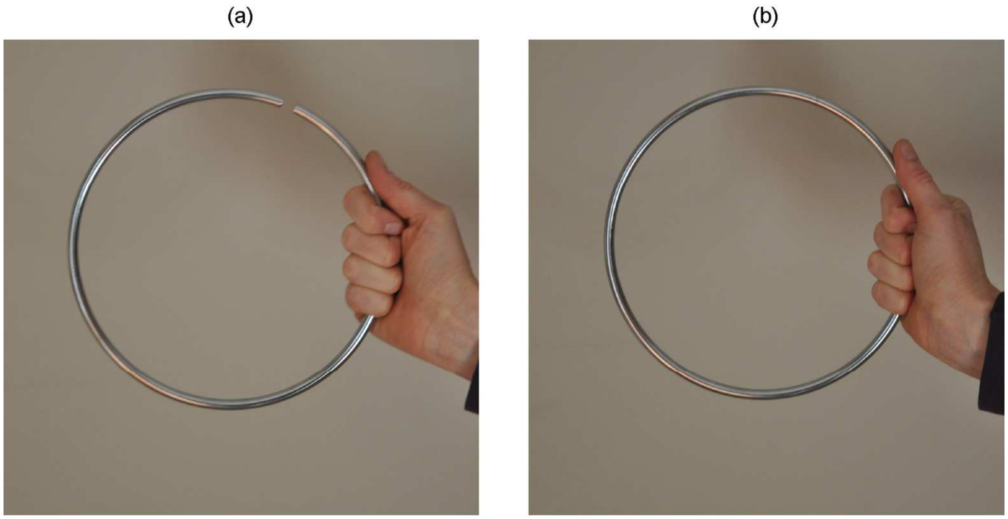

Figure 4: The main principle underlying the Chinese linking ring routine. One of the rings has a small opening (a), but when the opening is covered by the magician's fingers, the ring looks complete (b).
158x90mm (300 x 300 DPI)

(a) (b) (c)

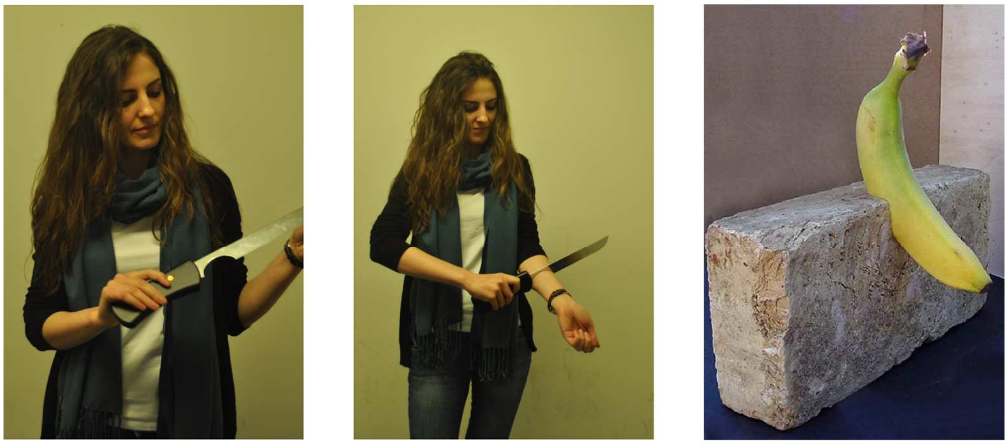

Figure 5: (a) The simple explanation behind the knife-through-arm trick is a hole in the blade. (b) When the arm is put into the hole, the knife appears to penetrate the arm, rather than the other way around.(c) Using essentially the same trick, it is also possible to create the illusion that a banana penetrates a brick (from Gerbino & Zabai, 2003).
158x79mm (300 x 300 DPI)

(a) (b)

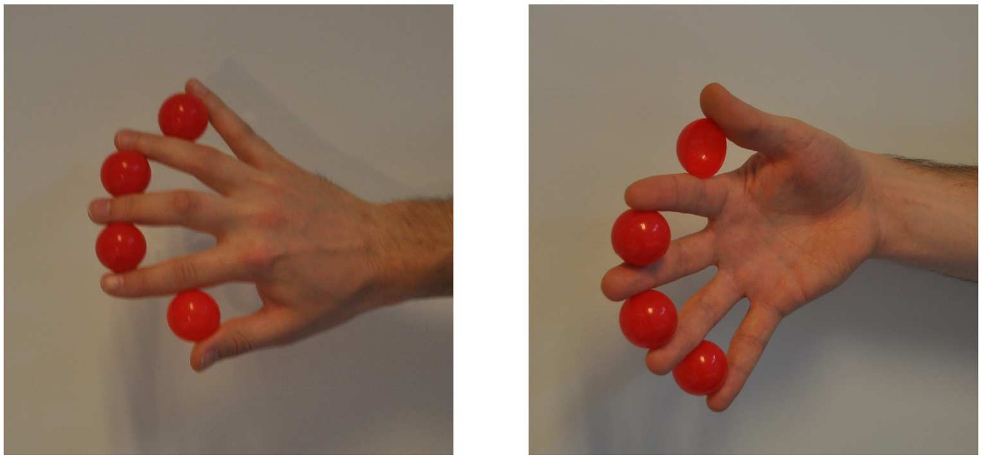

Figure 6: In the Chicago multiplying balls trick, the conjurer starts with a single ball held between his thumb and index finger, and successively makes additional balls appear until he ends up with showing four balls, as in panel (a). The main secret behind the trick is that the "ball" kept between the thumb and the index finger is actually just an empty semi-spherical shell (top of panel (b)) in which a second ball can be hidden. At the beginning of the routine, one complete ball is hidden in the shell. Using the middle finger, this ball is then flipped out of the shell and held between the index finger and the middle finger. After having produced this basic illusion, more balls can be produced by surreptitiously loading new balls into the shell while pretending to move the upper ball one step up in the "ladder" of fingers using the other hand. Then, the newly loaded ball can be produced from the shell in the same way as before.
158x79mm (300 x 300 DPI)

Figure 7: A demonstration of “amodal absence” inspired by a currently popular “visual joke” circulating in social media called “amodal nudity” or “bubble porn” (e.g. Hill, 2013; Bonnet, 2013). In panel (b), the objects on the table are occluded by a violet “bubbled” occluder. Note how difficult it is to imagine that the objects in (a) are really hidden behind the “bubbled” occluder in (b).
185x67mm (300 x 300 DPI)

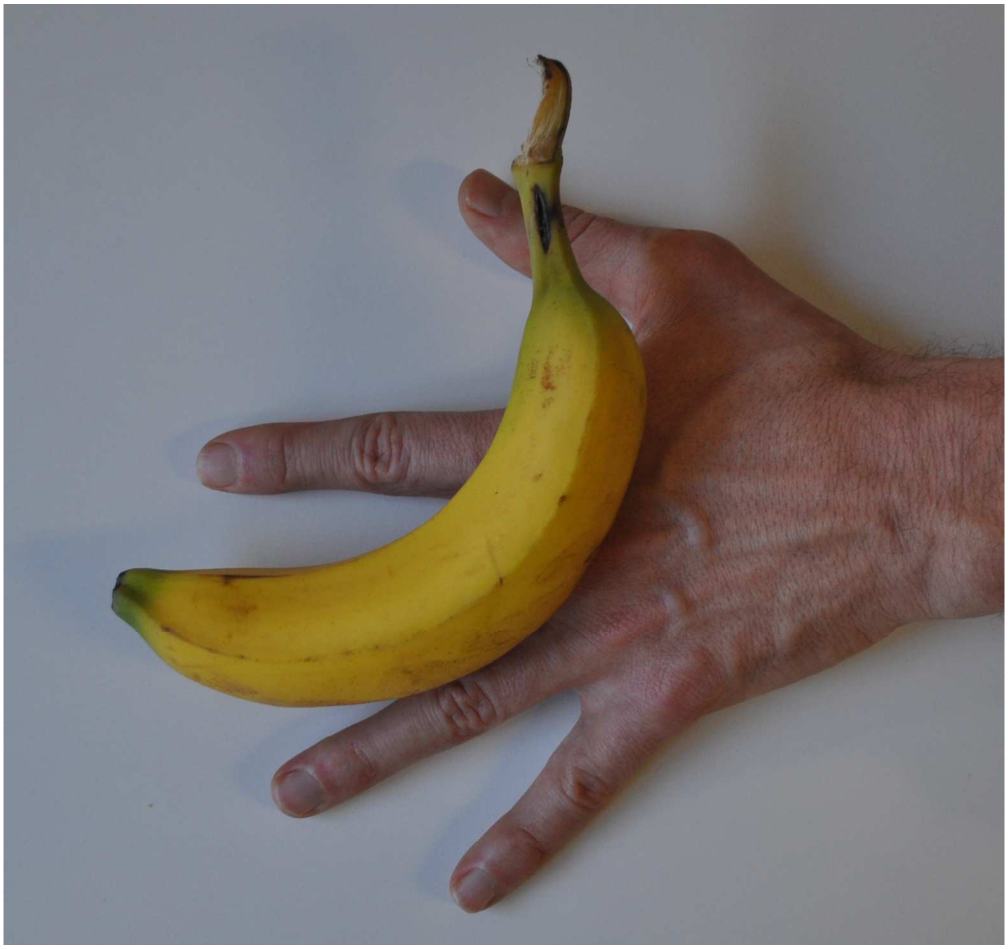

Figure 8: Although high-level knowledge makes us expect the middle finger to be there behind the banana, it is still experienced as curiously absent.
165x156mm (300 x 300 DPI)

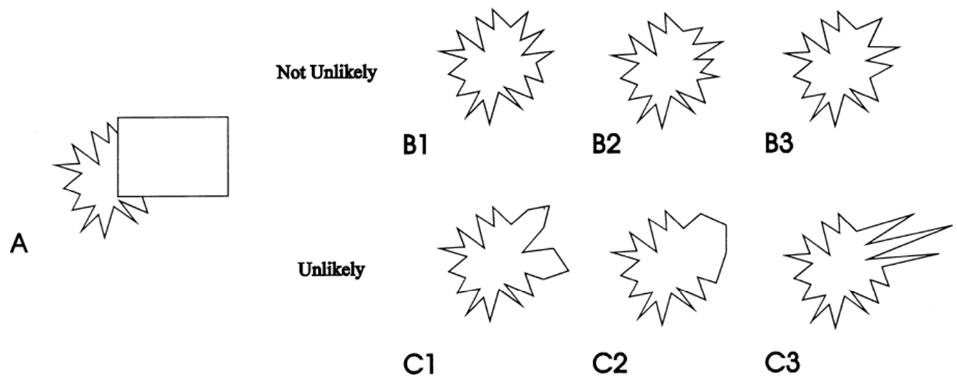

Figure 9: The shapes B1-B3 and C1-C3 are all logically possible completions of the partially occluded shape A. Some of them (B1-B3) are experienced as likely, while others (C1-C3) are experienced as unlikely. Thus, the perceptual representation of the hidden parts of the shape may be better conceived of as a set of possible shapes rather than a specific one. Reprinted from Acta Psychologica, 102(2), van Lier, R., Investigating global effects in visual occlusion: From a partly occluded square to the back of a tree-trunk. Pp. 203-220, Copyright (1999), with permission from Elsevier.
340x138mm (72 x 72 DPI)

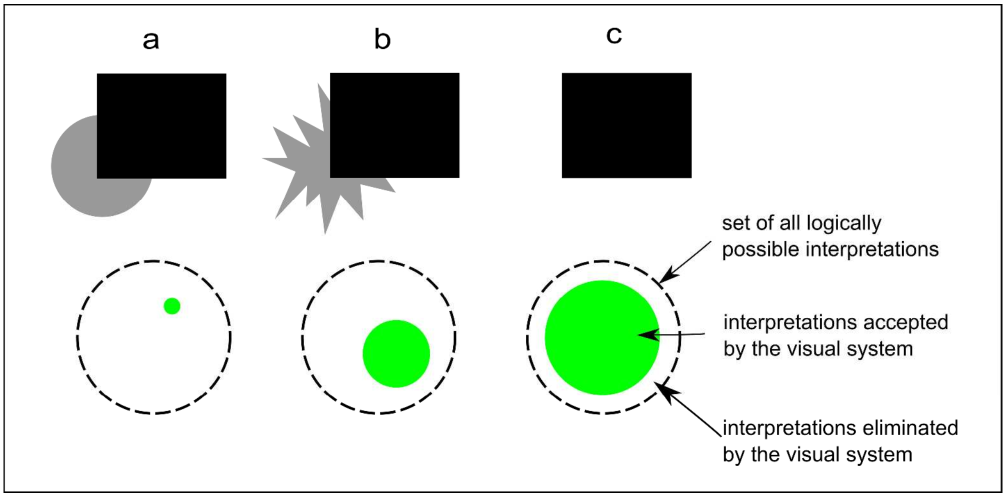

Figure 10: Illustration of how the perceptual system may generate increasingly fuzzy representations of occluded scene regions as the ambiguity of the stimulus increases. (a) The most well-known type of amodal completion. Here, the visual system creates a rather specific representation of the parts of the scene hidden behind the square: The visual system creates a representation which encompasses just a small subset (green disk) of the set of logically possible interpretations (dotted circle). (b) A more fuzzy kind of amodal completion (van Lier, 1999), where the visual system creates a representation encompassing a larger subset of the logically possible options. (c) In the case of total occlusion, the stimulus is even more ambiguous, but the visual system may create a representation which, although it is very fuzzy and unspecific, is more specific than the set of logically possible options. Hence, some of the logically possible representations would be eliminated by the visual system.

(a) (b)

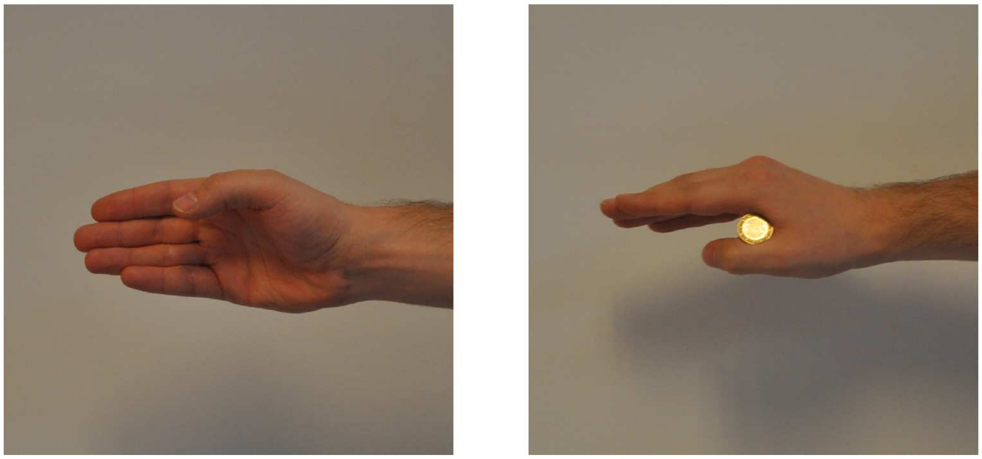

Figure 11: Simple coin production. The magician shows a seemingly empty hand, as in (a), and grasps a coin out of thin air. In reality, the coin is kept behind the thumb to begin with, as shown in (b).
158x79mm (300 x 300 DPI)

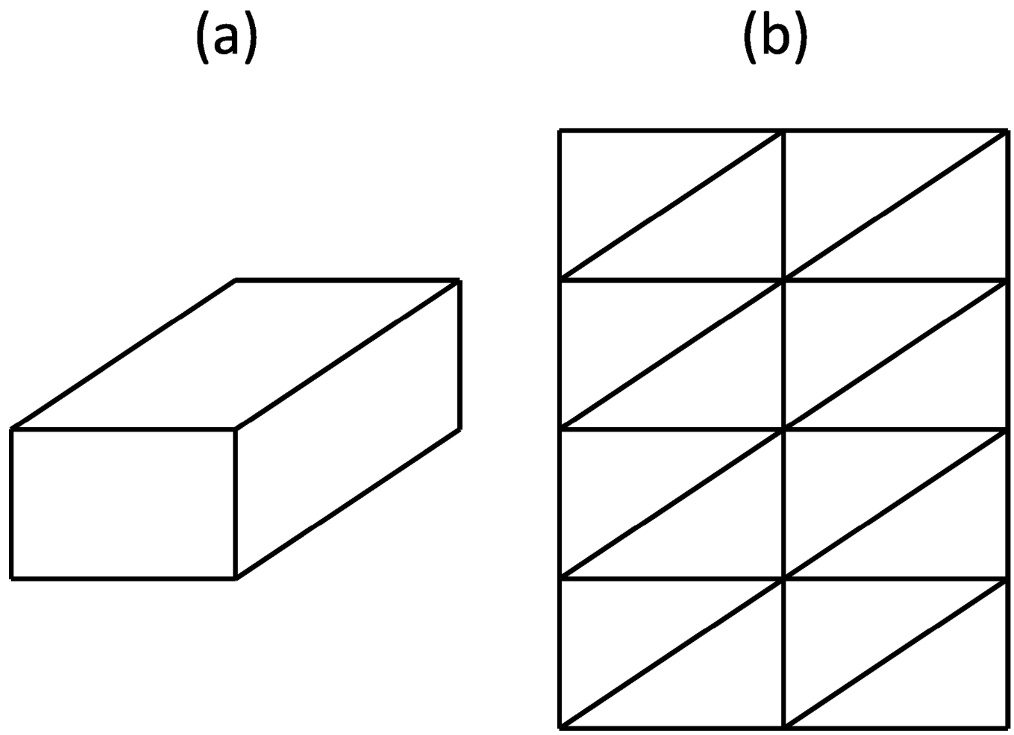

Figure 12: An example of “visual fixedness”: It is very difficult to see that the box in (a) is actually a part of the figure in (b). After Koffka (1935).

Figure 13: The chess figures on the top and on the bottom are actually identical, but the ones on top look white, while those at the bottom look black. Note that this illusion does not go away even though you know that the figures are in fact equal. You can verify this by covering up the surrounds. Reprinted by permission from Macmillan Publishers Ltd: Nature, Anderson, B. L., & Winawer, J. Image segmentation and lightness perception. Nature, 434(7029), 79-83, copyright (2005).
209x209mm (72 x 72 DPI)